

Compact Triband Dual F-Shaped Antenna for DCS/WiMAX/WLAN Applications

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Abstract—A novel and compact triband planar antenna geometry suitable for DCS/WLAN/WiMAX services is reported. The multiple metal strip geometry in dual F shape is printed on a substrate of dielectric permittivity 4.4 and thickness 1.6 mm. A truncated and asymmetrically placed ground structure is used for improved impedance matching. Feed position is also optimized for good antenna radiation performance. The geometry is simulated using High Frequency Structure Simulator. All the radiation characteristics of the antenna are validated experimentally and found in good agreement with simulation results. Performance of the proposed antenna is compared with other triband antennas reported in the literature. Measured radiation patterns and gain are also presented in this paper. The radiation patterns are validated by EMSCAN Corporation's RExpertTM application tool also.

1. INTRODUCTION

Increased functionality and complexity of modern electronic systems demand wireless connectivity capable of operating in multiple bands. Popular bands for this purpose are Global System for Mobile communication (GSM-920 MHz), Digital Cellular System (DCS-1800 MHz), Industrial Scientific and Medical radio frequency band (ISM-2.4 GHz), Wireless Local Area Network (WLAN-2.4/5.25/5.77 GHz) and Worldwide Interoperability for Microwave Access (WiMAX-2.7/3.5/5.79 GHz). A multiband antenna is one of the key elements in the RF front end of such a system. Planar antennas are widely accepted by communication system designers due to its advantages such as miniaturization, cost effectiveness, multiband performance and the easiness to integrate with other system components. This heavy demand results in remarkable growth of design and development of printed antennas.

Different techniques, such as slot loaded patch, meander lines, stacked layers, parasitic elements, defects in ground structure (DGS), Metamaterial structures [1–16], are used for exciting the antenna at multiple frequencies. In slot loading technique, appropriately placed slots in the resonating patch with different shapes like inverted U [1–3], I [4], hexagon [5], circular [6], and L shape [7] are effectively used to produce additional bands. Karimian et al. [8] reported an antenna with both open ended and short ended slots connected by a metal via to a microstrip line. These slots are useful for producing current paths of different lengths which result in multiple resonances. In [9, 10] meander line structures above the ground plane (heights of 4 mm and 7 mm respectively) are used for producing resonance at desired frequency. This technique — meander lines — helps to reduce the antenna area even though the ground size is large (70 mm × 40 mm and 40 mm × 40 mm respectively) which can be common for the entire circuit area. Use of small slot in the ground plane (DGS) for optimizing the band width is also demonstrated in [9]. Patel et al. [11] demonstrated effective use of defects — L and U shaped slots — introduced in ground plane for providing reactive components internally to produce additional bands.

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A dual-band antenna with E shaped stub in [12] is converted to an E ring structure by introducing E shaped slot in the stub to excite the antenna at a third frequency. In [5], design of a triple band antenna started with a hexagon shaped geometry for 5.5 GHz band. It is converted to a dual-band (2.45 and 5 GHz) antenna by inserting a hexagon shaped slot in the patch. This geometry is then modified by adding a half hexagon shaped stub to produce the third resonance at 3.5 GHz. Two reconfigurable antennas are reported in [13] and [14]. The antenna in [13] is a microstrip patch antenna with an E shaped slot in the stub which produces two bands at 2.4 GHz and 3.6 GHz. An inverted T shaped parasitic element is added to the modified ground plane to produce an additional resonance at 5.5 GHz. This parasitic element can be electrically connected to the ground through a PIN diode when single band performance at 5.5 GHz alone is required. In [14] a hook shaped metal strip antenna with 1 mm slot at the middle to connect a lumped element switch is proposed. It can operate either in 2.45/5.13 GHz bands or 3.49/5.81 GHz bands based on ON/OFF status of the switch. Chu and Shirai demonstrated the effective use of metamaterial structures for producing multiple bands [16].

In this paper, a compact triband planar antenna is presented. A planar geometry with back to back F shaped metallic strips as shown in Fig. 1(a) is used for exciting the resonances at 1.89, 3.5 and 5.5 GHz bands (DCS/WLAN /WiMAX). A modified ground structure is used to optimize the performance in different bands. Simulation results using High Frequency Structure Simulator (HFSSTM) software from Ansoft Corporation [17] and measured results are compared and presented. Performance of the proposed antenna is also compared in Table 2 with other similar antennas reported in the literature.

2. ANTENNA DESIGN

It has been shown that E and F shaped elements are suitable for producing multiple bands for WLAN/WiMAX applications [2, 4, 6, 8, 11]. In this design a back to back F shaped metallic strip is used as the primary resonating element.

The proposed triband antenna geometry is shown in Fig. 1. Evolution of antenna geometry began with a single metallic strip, length equal to half wavelength in the substrate at midband, as shown in Fig. 2(a) on a 20 mm \times 20 mm substrate with thickness 1.6 mm, relative permittivity $\epsilon_r = 4.4$, and loss tangent $\tan \delta = 0.02$, which could excite the resonance at 3.8 GHz. This element is modified with an additional element in back to back arrangement with a narrow gap between them and extended to right edge from top, as shown in Fig. 2(b) to produce lower resonance band near 2 GHz. The total length is tuned for 1.8 GHz band. One more additional horizontal element is added to the right side of this second vertical element as shown in Fig. 2(c) and optimized the entire structure to excite the upper band at 5.5 GHz. The other horizontal elements, as shown in Fig. 1, are added to improve the impedance matching, and all the elements are tuned to achieve the desired application bands. The ground plane conductor is truncated and placed asymmetrically for improvement of impedance matching. The feed point is positioned at 14.05 mm from left edge of the geometry for the best

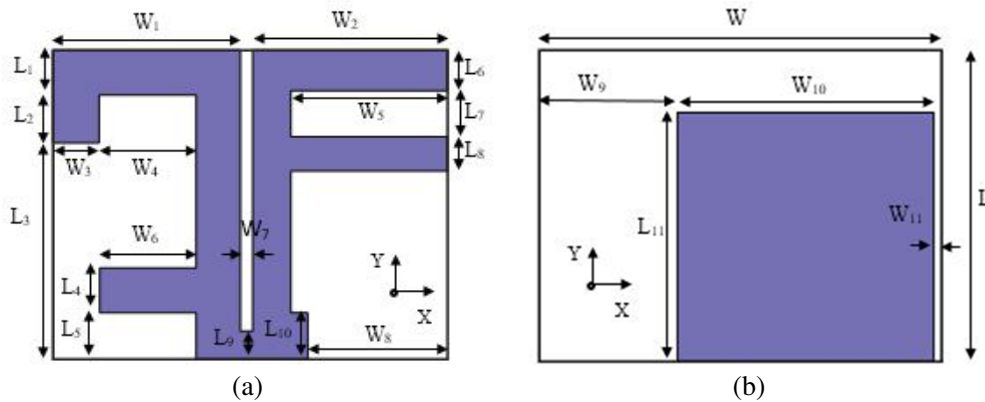


Figure 1. Geometry and parameters of the proposed antenna, (a) top view and (b) bottom view.

performance of the antenna. The final structure resonates at 1.89 GHz, 3.5 GHz and 5.5 GHz bands and is suitable for DCS/WLAN/WiMAX applications. The size of the final antenna geometry is 25.8 mm × 20 mm × 1.6 mm, and all the dimensions are given in Table 1.

Table 1. Dimensions of the antenna geometry (all dimensions are in millimeters).

L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	L_{11}	L
2.9	3.1	14	2.9	3	2.6	3	2.2	1.8	3	16	20
W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8	W_9	W_{10}	W_{11}	W
12.25	12.75	3	6.35	10.25	6.3	0.8	9.15	8.85	16.45	0.5	25.8

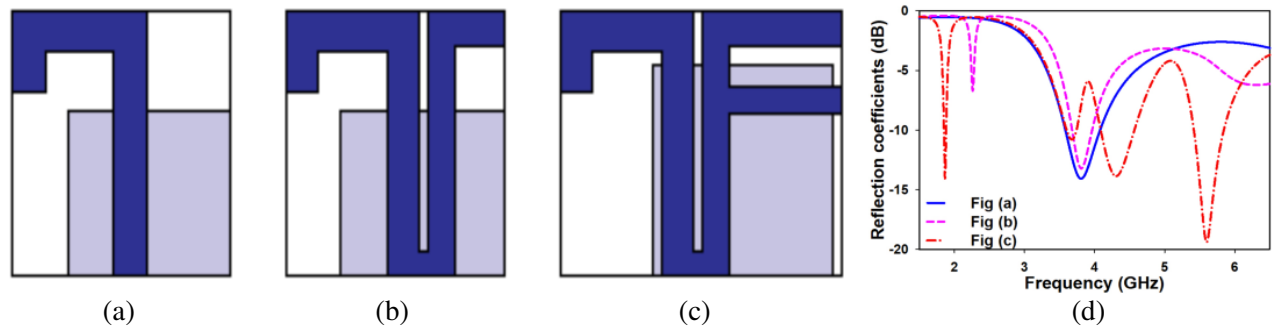


Figure 2. Evolution of the antenna geometry, (a) single band geometry, (b) dual band geometry, (c) triband geometry and (d) corresponding simulated reflection characteristics.

3. RESULT AND DISCUSSION

The antenna is fabricated using conventional photolithographic technique and characterized using Agilent Vector Network Analyzer E8362B. Top and bottom views of the fabricated antenna are given in Figs. 3(a) and (b), respectively. Simulated and measured reflection characteristics are shown in Fig. 4. The measured reflection characteristics is in good agreement with the simulation result. The lower band resonance is centered at 1.89 GHz with 10 dB impedance bandwidth of 170 MHz. In the measured result, it is observed that the resonances at 3.5 GHz and 4.28 GHz are merged and result in a wide band extending from 3.2 GHz to 4.5 GHz (33.8% band width). The third band is from 5.13 GHz to 6.2 GHz (18.8% band width). These two wide bands are sufficient to support the requirements of WLAN (5.15–5.35 and 5.72–5.85 GHz) and WiMAX (3.4–3.69, 5.25–5.85 GHz) at 5.5 and 3.5 GHz bands [18].

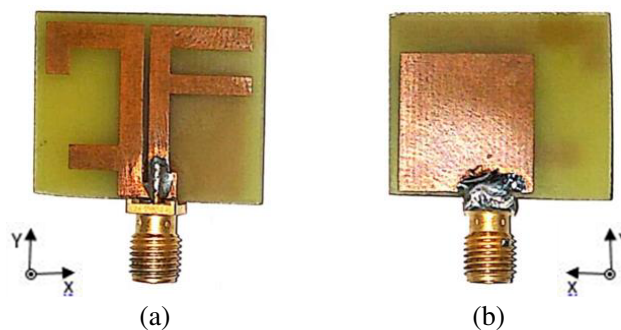


Figure 3. Top and bottom views of the fabricated antenna, (a) top view and (b) bottom view.

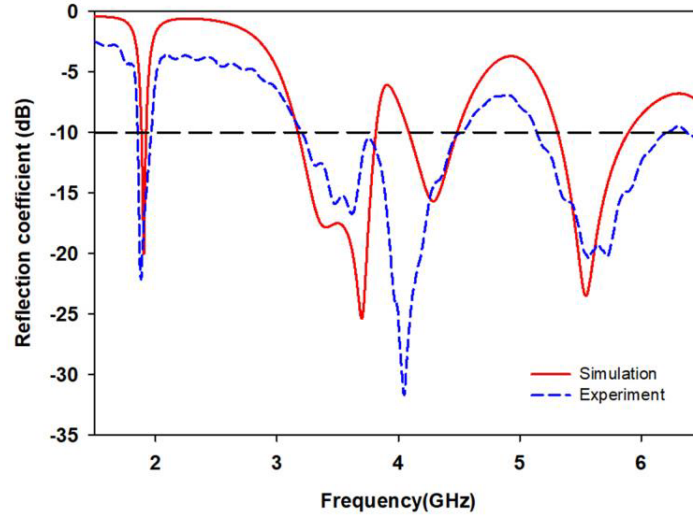


Figure 4. Simulated and measured reflection coefficients (S_{11}) of the proposed antenna.

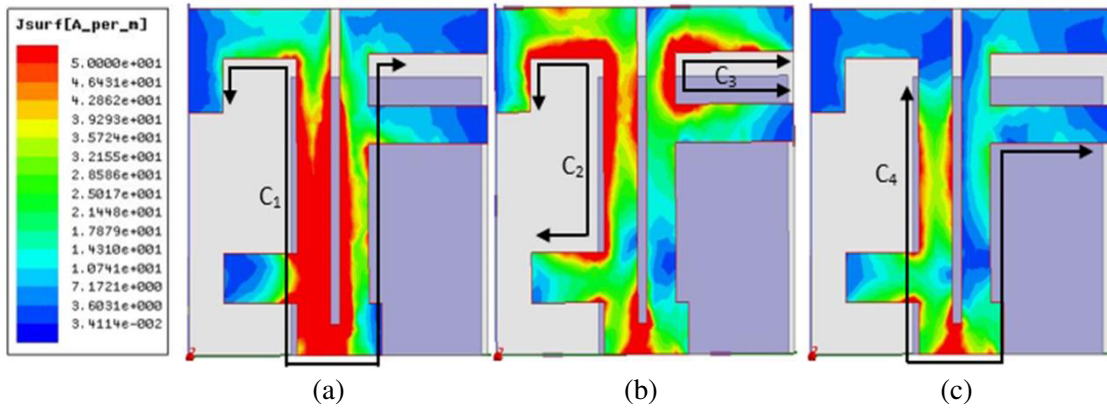


Figure 5. Surface current distributions at (a) 1.89 GHz (b) 3.5 GHz and (c) 5.5 GHz.

Surface current distributions at 1.89 GHz, 3.5 GHz and 5.5 GHz are shown in Fig. 5. At 1.89 GHz the current is mainly distributed in vertical elements and extended horizontal elements from the top, on both the sides as indicated by curve “ C_1 ” in Fig. 5(a). The length “ C_1 ” is approximately equal to half wavelength in substrate at this frequency. Fig. 5(b) makes it clear that two paths, marked by curves “ C_2 ” and “ C_3 ”, in the structure are contributing towards the resonance at 3.5 GHz. These current path lengths are slightly different but close to $\lambda_g/2$ at mid band. This current distribution explains the increased bandwidth at this frequency. At 5.5 GHz surface current is distributed along “ C_4 ” as shown in Fig. 5(c). This path length is nearly equal to a wavelength in substrate at this frequency. C_1 , C_2 , C_3 and C_4 are 51.5, 26.95, 23.5 and 36 millimeters in length.

The measured co-polarization and cross-polarization patterns on XZ and YZ planes at 1.89 GHz, 3.5 GHz and 5.5 GHz are given in Figs. 6(a) to (f). The patterns of 1.89 GHz and 3.5 GHz are nearly omnidirectional. In the higher band, the pattern slightly deviates from the omnidirectional behavior. The 3D radiation pattern of 1.89 GHz band, plotted using EMSCAN Corporation’s RFXpertTM, is shown in Figs. 7(a) and (b). This also confirms the omnidirectional nature in the lower band. The measurement setup with RFXpertTM is given in Fig. 8. Gain and efficiency plots are given in Fig. 9. The measured peak gains are 0.136, 2.12 and 3.55 dBi in the 1.89 GHz, 3.5 GHz and 5.5 GHz bands, respectively, and the corresponding efficiencies are 34.5%, 80% and 83.9%. The reduced size of the antenna and the truncation of its ground plane affected the gain in lower band.

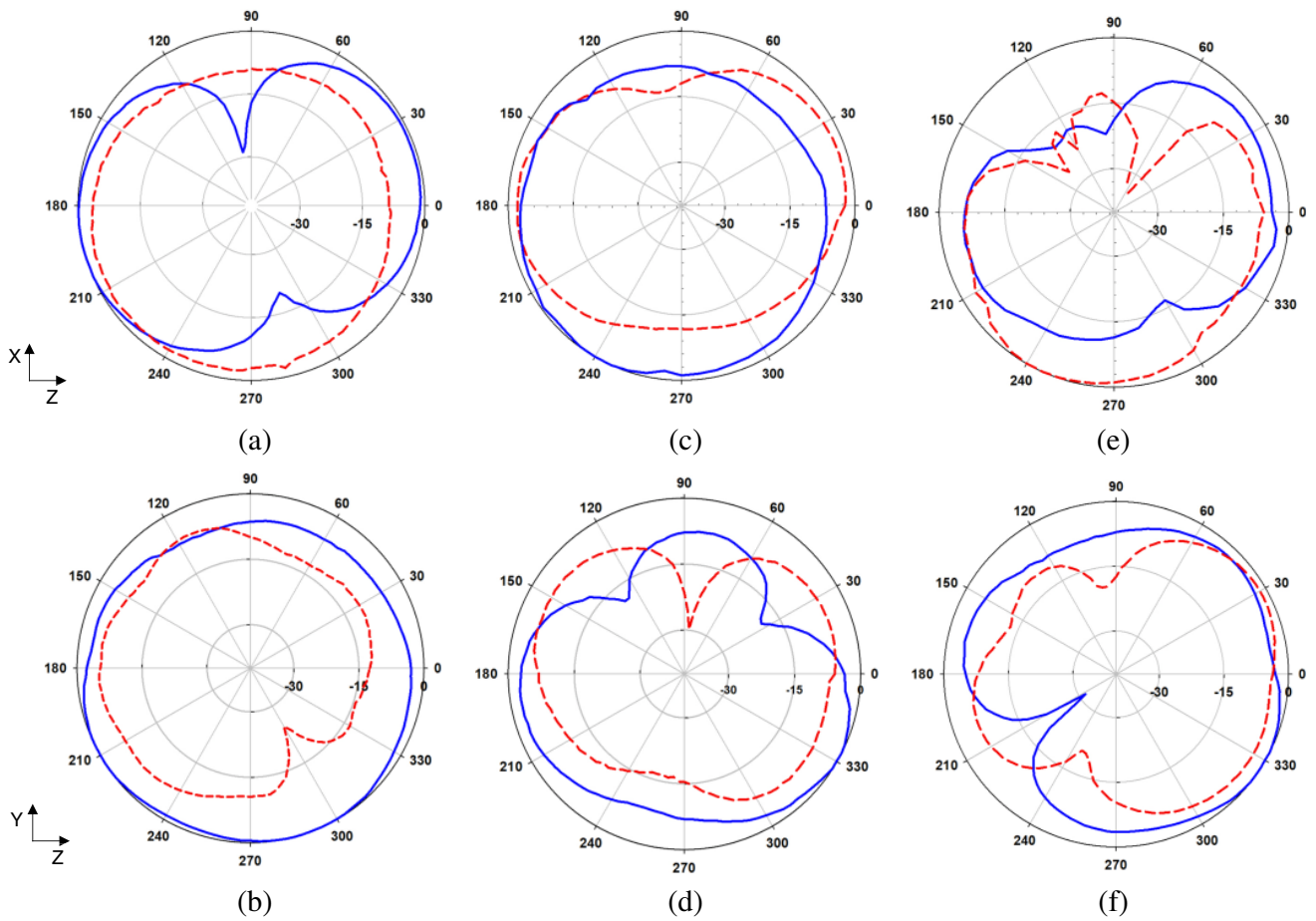


Figure 6. Measured radiation patterns of the antenna in XZ and YZ planes at (a)–(b) 1.89 GHz, (c)–(d) 3.5 GHz, (e)–(f) 5.5 GHz. (Blue: Co-Pol, Red Dashed: Cro-Pol.).

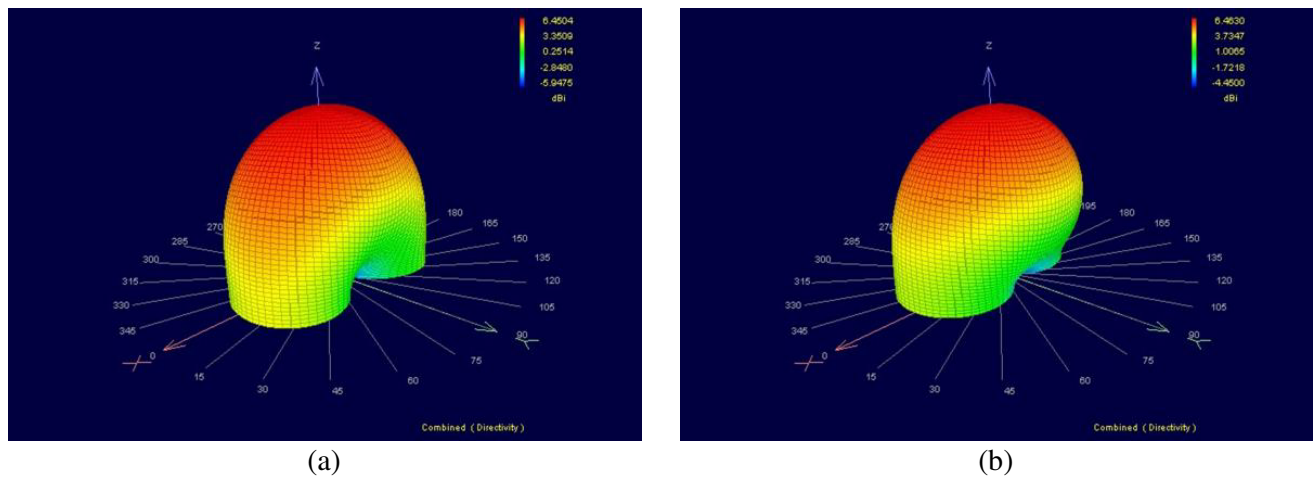


Figure 7. Three dimensional radiation patterns of 1.89 GHz band towards (a) $+z$ direction and (b) $-z$ direction of the antenna, measured using RFXpert™. X and Y directions shown in the diagram are axis of the test bed.



Figure 8. 3D pattern measurement setup using EMSCAN Corporation's RFXpert™.

Table 2. Performance comparison of the proposed antenna with other similar antennas reported in the literature.

Reference/ Year	Substrate parameters	Antenna size in millimeter	Ground size (mm)	Operating bands in GHz	Peak Gain in dBi
[9], 2014	FR4 with $\epsilon_r = 4.4$, $\tan\delta=0.02$	10 x 5	70 x 40	2.4 , 5.5	1.99, 3.71
[12], 2014	FR4 with $\epsilon_r = 4.4$, $\tan\delta=0.02$	30 x 30 x 0.8	30 x 30	2.4, 5.2, 5.8	Not reported
[5], 2015	FR4 with $\epsilon_r = 4.6$, $\tan\delta=0.02$	26 x 25 x 1	26 x 25	2.5, 3.5, 5.5	1.73,1.86, 2.18
[18], 2015	FR4 with $\epsilon_r = 4.4$, $\tan\delta=0.02$	31 x 33 x 1	31 x 14	2.5,3.5, 5.5	Nearly 2.9, 3.1, 4.5
[1], 2016	FR4 with $\epsilon_r = 4.4$, $\tan\delta=0.02$	30 x 35 x 1.5	30 x 15	2.45, 3.19-6.44	0.2, 2.9
[14], 2017	FR4 with $\epsilon_r = 4.5$, $\tan\delta=0.019$	22 x 40 x 1.6 (Reconfigurable)	22 x 9	2.45, 3.49/ 5.13, 5.81	1.72, 2/ 2.08, 2.96
[15], 2018	FR4 with $\epsilon_r = 4.4$, $\tan\delta=0.02$	45 x 17 x 1.6	45 x 17	0.868, 2.4	1.18, 2.1
[11], 2018	FR4 with $\epsilon_r = 4.4$, $\tan\delta=0.02$	20 x 21 x 1.6	20 x 21	0.926, 1.57, 2.47	0.32, 1.2, 1.5
[16], 2018	FR4 with $\epsilon_r = 4.4$, $\tan\delta=0.02$	57.2 x 31.2 x 1.6	57.2 x 31.2	0.8, 2.45, 3.5, 5.5	-8.12, -1.31, 1.46, 3.66
Proposed antenna	FR4 with $\epsilon_r = 4.4$, $\tan\delta=0.02$	25.8 x 20 x 1.6	16.45 x 16	1.89, 3.5, 5.5	0.136, 2.12, 3.55

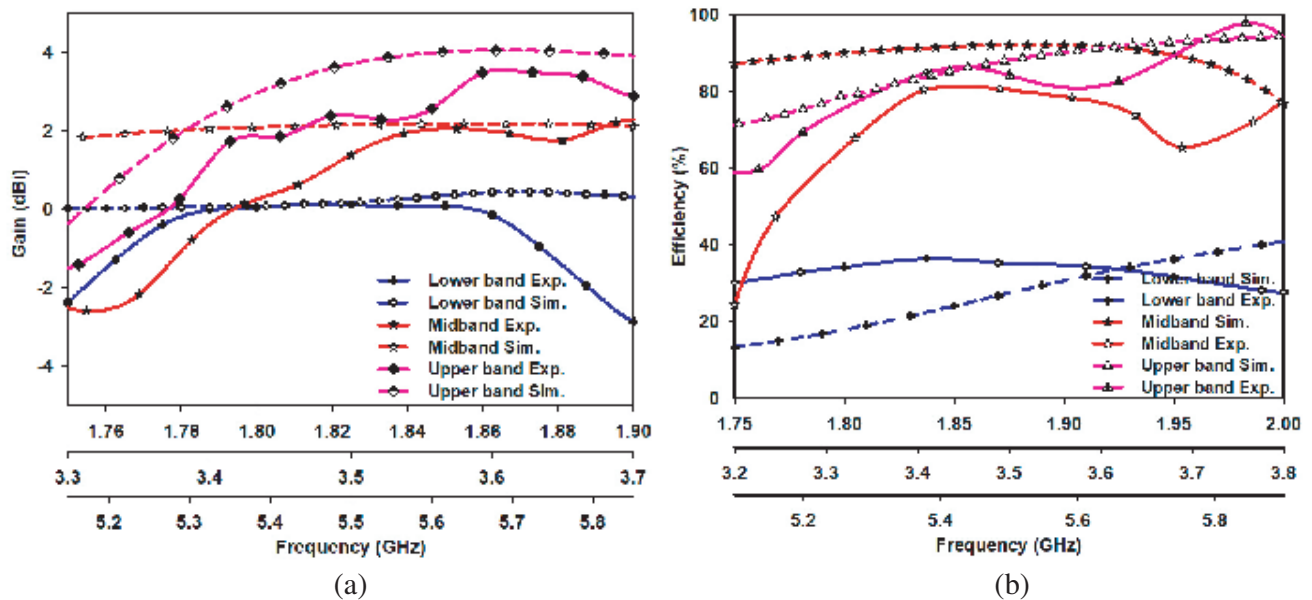


Figure 9. Simulated and experimental (a) Gain and (b) Efficiency of the proposed antenna. Blue, Red and Pink indicate lower, mid and upper bands. Solid and broken lines represent experimental and simulation results.

4. CONCLUSION

A novel antenna geometry suitable for DCS/WLAN/WiMAX services in 1.89/3.5/5.5 GHz bands is developed and experimentally validated. Simulated and experimental results are discussed. The proposed geometry offers better gain than the configurations in [1, 5, 14] in the higher bands for a much smaller overall dimension. As far as the lower band is concerned, gain is moderate, but the proposed geometry is of smaller dimension than [15, 16]. The realized peak gains in the bands are 0.136, 2.12 and 3.55 dBi, respectively. A performance comparison of the proposed antenna with other similar antennas reported in literature is presented in Table 2. The antenna is designed on a low cost and easily available FR4 substrate. The geometry proposed is compact (25.8 mm × 20 mm × 1.6 mm) with respect to other antennas compared, and the performance is comparable.

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